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MHD FLOW IN POROUS MEDIUM WITH INDUCED FIELD AND MASS TRANSFER EFFECT AT CONSTANT TEMPERATURE GRADIENT

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ABSTRACT

Amagnetohydrodynamic flow of incompressible viscous fluid past a steadily moving infinite vertical porous plate is discussed under the action of transverse magnetic field. Considering a heat flux within the medium due to the constant temperature gradient at the plate, the effects of induced field and fluid concentration on flow and temperature are discussed for smaller values of Eckert number. The expressions and analytical solutions for fluid velocity, temperature, fluid concentration and induced field are obtained following Raptis [1]. The results are shown graphically followed by discussion and conclusion.

KEY WORDS: Magnetohydrodynamic, Induced-field, Mass-transfer, Porous-medium, Temperature-gradient.

1. INTRODUCTION

Problems of free and forced convective flow under the action of induced magnetic field are frequently encountered in various physical and engineering fields. The phenomenon of natural convective flow is not often caused entirely by the effect of temperature gradients but also due to the applied magnetic field which in turn induces another magnetic field that influence the flow largely. The study of magneto-hydrodynamic flow in the presence of porous walls has many applications in various fields of science and technology. Soundalgekar& Bhatt [1] have studied the oscillatory MHD channel flow and heat transfer. Soundalgekar & Bhatt[2] have studied the oscillatory MHD channel flow and heat transfer. Raptis & Soundalgekar [3] have studied the MHD flow past a steadily moving infinite vertical porous plate with mass transfer and constant heat flux. Drake [4], Soundelgekar [5], Pop [6], Dube [7], Singh [8], Das and Sanyal [9], Mana [10], Seth and Banerjee [11], Mittal et al.[12], and many other authors have studied various problems of MHD flow taking induced magnetic field into account. Singh and Singh [13] has studied on MHD effects on flow of viscous fluid with induced magnetic field.

Motivated by the above referenced works and the numerous possible applications in the field Science & Technology specially in Geological Science, Astronomical Science and Biophysical Science, it is our interest to investigate a steady, fully developed MHD convective heat and mass transfer problem of an incompressible fluid flow where an incompressible electrically conducting viscous fluid moves past a steadily moving infinite vertical porous plate under the action of uniform magnetic field that induces another field transverse to it. The expressions and analytical solutions for fluid velocity, temperature, concentration and induced field are obtained following Raptis [1]. The effects of flow parameters like Schmidt Number, Hartmann Number, Prandtl Number, Magnetic Prandtl Number on fluid velocity, temperature, magnetic field, mass transfer, skin-friction and rate of heat transfer, are analyzed graphically and compared to those in absence of induced field. The results observed some significant differences in flow pattern in variation of flow parameters.

2. FORMULATION OF THE PROBLEM

The flow of an electrically conducting, incompressible viscous fluid is considered. The plate which is vertical and porous is assumed to be moving steadily in the vertical up- ward direction along which the x-axis is chosen. The y-axis is chosen normal to the plate. Under these conditions, the basic equations of combined free and forced convective flow,under usual Bossinesq's approximation are derived by Raptis & Soundalgekar [3].

3. ASSUMPTIONS

(i) The level of concentration of foreign masses are very low such that the Soret and Dufour are negligible.

(ii) The flow is a free and forced convective flow under Bossinesq's approximatnion.

(iii) All the variables (i.e. velocity field, magnetic field, temperature field and mass concentration) are only dependent y-axis.

(iv) Hall Effect, Polarization effect, Buoyancy effect and the effects of heat radiation are negligible.

4. MATHEMATICAL FORMULATION

We consider a fully developed laminar unidirectional flow of an incompressible, electrically conducting incompressible fluid past a vertical porous plate. The plate is assumed to be moving steadily in the infinite vertical upward direction along which x-axis is chosen, while y-axis is normal to the plate. Let a uniform magnetic field $\bar{H}(y)$ is applied along the motion of the plate that induced magnetic field $\bar{B} = \mu_e H(y)$ transverse to the motion of the plate.

5. GOVERNING EQUATIONS

Under above assumptions, the velocity and magnetic field magnetic field components are

$$\bar{V} = [\, u(y),\, v_o,\, 0\,]; \quad \bar{B} = [\, H(y),\, \mu_e H(y),\, 0\,] \tag{1}$$

H &μ_e are being magnetic flied applied and magnetic permeability of the medium.

Under above assumptions and the geometry of the problem, the governing equations are as follows.
Equation of conservation of momentum

$$V_0\frac{\partial u}{\partial y} = \upsilon(\partial^2 u / \partial y^2) + \mu_e H(y)\frac{\partial H}{\partial y} + g\,\beta\,(T - T_\infty) + g\,\bar{\beta}\,(C - C_\infty)\,\} \tag{2}$$

Equation of thermal diffusivity

$$\rho C_p\,(V_0\frac{d\ T}{dy}) = k\,(d^2T / dy^2) + \mu\ (\frac{\partial u}{\partial y})^2 + \frac{1}{\sigma}(\frac{\partial H}{\partial y})^2 \tag{3}$$

Equation of Mass diffusivity

$$(u\ \frac{dC}{dy}) = D\,(\frac{dC}{dy})^2 \tag{4}$$

Equation of Magnetic diffusivity

$$\frac{\partial B}{\partial t} = \nabla \times (v \times B) + \frac{1}{\sigma}\nabla^2 H \tag{5}$$

Introducing non-dimensional quantities as given below

$u' = \frac{u}{Vo}$; $y' = v_0\frac{Y}{\upsilon}$ $C' = (C - C_\infty) / (C_W - C_\infty)$; $T' = [(T - T_\infty)k\,V_0] / (q\upsilon)$;

$H' = (H / \upsilon_0)\sqrt{(\mu_e / \rho)}$, q is a quantity with dimension $M\,T^{-3}$ (6)

Substituting above non-dimensional quantities and removing primes, equations (2) – (5) are as follows.

$$-\ \frac{\partial u}{\partial y} = G_m C + G_r T + \frac{\partial^2 u}{\partial y^2} + M\frac{\partial H}{\partial y} \tag{7}$$

$$\frac{1}{Pr}[\ \frac{\partial^2 H}{\partial y^2}\ ] + \ \frac{\partial H}{\partial Y} + M\frac{\partial U}{\partial y} = 0 \tag{8}$$

$$\frac{\partial C}{\partial y} + \frac{1}{Sc}\ [\frac{\partial^2 C}{\partial y^2}] = 0 \tag{9}$$

$$\frac{\partial^2 T}{\partial y^2} + P_r\frac{\partial T}{\partial Y} = -\ PrE\,[(\frac{\partial u}{\partial y})^2 + \frac{1}{Pm}\left(\frac{\partial H}{\partial y}\right)^2] \tag{10}$$

where,
$\upsilon = \frac{\mu}{\rho}$, Kinematic viscosity ; μ = Coefficient of viscosity of the medium ; T = Fluid temperature ; β = Volumetric Coefficient thermal expansion ; $\bar{\beta}$ = Volumetric Coefficient of mass transfer ; α = thermal diffusivity ; $\upsilon_m = \mu_e\sigma$ $(magnetic\ diffusivity)$; $\sigma = electrical\ conductivity$, μ_e magnetic permeability of the medium ; C = fluid Concentration, β = Volumetric Coefficient thermal expansion ; $\bar{\beta}$ = Volumetric Coefficient of mass transfer ; D = Coefficient of mass transfer ; $S_c = \frac{D}{\upsilon}$ Schmidt Number ; $M = (H / \upsilon_0)\sqrt{(\mu_e / \rho)}$, Magnetic Hartmann Number,

$P_m = \mu_e\sigma\upsilon$ Magnetic Prandtl Number; $G_r = (g\,\beta\,q\,\upsilon^2) / (k\,v_0^{\,4})$, Grashoff Number ;

$G_m = [g\,\beta\upsilon\,(C_w - C_\infty)] / (v_0^{\,3})$, Modified Grashoff Number;

$P_r = (\mu C_p / k)$, Prandtl Number; $E = (k\,v_0^{\,3})/(q\upsilon C_p)$, Eckert Number

The corresponding non-dimensional boundary conditions are

$y = 0,\quad u = U,\quad (\frac{dT}{dy}) = -1,\quad C = 1,\quad H = K$

$\&\quad y \to \infty,\quad u \to 0,\quad T \to 0,\quad C \to 0,\quad H \to 0$ (11)

Where U and K are two assumed values for u and H respectively suitable to the problem

6. SOLUTIONS OF GOVERNING EQUATIONS

Solution for Mass Transfer equation under above boundary conditions is

$$c(y) = e^{-\ S_c\ y} \tag{12}$$

In order to get solution of the governing equations (7 – 10) we consider following series expansion in terms of E, the Eckert Number.

$u = u_0 + E\,u_1 + 0(E^2)$

$H = H_0 + E H_1 + 0(E^2)$

$T = T_0 + E T_1 + 0(E^2)$ (13)

Using above expansions the governing equations can be divided in increasing order of E (i.e. 1st , 2nd ----) as follows.

1st order of equations

$\frac{\partial^2 u_0}{\partial y^2} - \frac{\partial u_0}{\partial y} + M\frac{\partial H_0}{\partial y} + G_r T_0 + G_m C = 0$ (14)

$(1/P_r)\ \frac{\partial^2 T_0}{\partial y^2} + \frac{\partial T_0}{\partial y} = 0$ (15)

$(1/P_m)\ \frac{\partial^2 H_0}{\partial y^2} + \frac{\partial H_0}{\partial y}(1+M) = 0$ (16)

Corresponding non-dimensional boundary conditions are

$y = 0, \quad u_0 = U, \quad (\frac{dT_0}{dy}) = -1, \quad C=1, \quad H_0 = K$

& $\quad y \to \infty, \quad u \to 0, \quad T \to 0, \quad C \to 0, \quad H \to 0$ (17)

2nd order of equations

$\frac{\partial^2 u_1}{\partial y^2} - \frac{\partial u_1}{\partial y} + M\frac{\partial H_1}{\partial y} + G_r T_1 + G_m C = 0$ (18)

$\frac{\partial^2 T_1}{\partial y^2} + \frac{\partial T_1}{\partial y} = -Pr\ [\ (\frac{\partial u_0}{\partial y})^2 + \frac{1}{Pm}(\frac{\partial H_0}{\partial y})^2]$ (19)

$(1/P_m)\ \frac{\partial^2 H_1}{\partial y^2} + \frac{\partial H_1}{\partial y} + M\ \frac{\partial u_1}{\partial y} = 0$ (20)

7. VISCOUS-DRAG AND HEAT-TRANSFER

The physicalquantities of ourinterestat the plate are Skin friction coefficients $[\tau]_{y=0}$ and rate of heattransfer $[Q]_{y=0}$ are as follows.

$\tau = -\mu\left(\frac{du}{dy}\right)_{y=0}$ and $N_u = -\frac{1}{k}[\ \frac{dT}{dy}\ ]_{y=0}$

Using (6), the non-dimensionalviscous drag per unit length i.e. Skin friction and rate of heattransferat the plate y = 0 are given as

$\tau_p = -\left(\frac{du}{dy}\right)_{y=0}$ (21)

$N_u = -[\ \frac{dT}{dy}\ ]_{y=0}$ (22)

Where,

$\left(\frac{du}{dy}\right)$ and $\left(\frac{dT}{dy}\right)$,are the non-dimensional gradients of velocity and temperature with in the medium.

8. SOLUTION OF GOVERNING EQUATIONS.

The solutions of governing equations (14)to (20)under their boundary conditions are as follows.

$T_0 = -\frac{1}{Pr}e^{P_r y}$ (21)

$H_0 = C_1 e^{m_1 y} + (k_5 - c_1)e^{m_2 y} - k_3 e^{P_m y} + k_4 e^{-S_c y}$ (22)

$u_0 = a_1 e^{m_1 y} + a_2 e^{m_2 y} - a_3 e^{S_c y} + a_4 e^{P\ m y}$ (23)

$k_1 = p_{m+1,}\ k_2 = P_m(M^2 - 1),$

$$k_3 = \frac{MP_{mG_r}}{p_m({p_m}^3 + k_1 p_m - k_2 p_m)}$$

$$k_4 = \frac{p_{mMG_m}}{-{s_c}^3 - k_{1s_c} + k_2 s_c}$$

$$k_6 = \left(\frac{m_2}{Mp_m} + 1\right) - \left(\frac{m_1}{MP_m} + 1\right), \qquad k_5 = K - (k_4 - k_3)$$

$$k_7 = k_5\left(\frac{m_2}{MP_m} + 1\right) + k_4\left(1 + \frac{s_c}{MP_m}\right) + k_3\left(1 + \frac{P_r}{MP_m}\right)$$

$$m_{1,2}=\frac{k_1\pm\sqrt{{k_1}^2+4k_2}}{2}\quad,\qquad m_{5,6}=\frac{-k_6\pm\sqrt{{k_2}^2+4k_7}}{2}$$

K_8=p_r+1 ; k_9= $p_r(1-M^2)$

$$m_{3,4}=\frac{-k_8\pm\sqrt{k_8}^2-4k_9}{2}$$

$c_1=\frac{U+k_7}{k_6}$ c_2=k_5-c_1 ,$a_1=-(\frac{m_1}{Mp_m}+1)(\frac{U+k_7}{k_6})$,

$a_2=\left(k_5-\frac{U+k_7}{k_6}\right)(\frac{m_2}{MP_m}+1)$, $a_3=k_4\left(1-\frac{s_c}{Mp_m}\right)$, $a_4=k_3(1+\frac{p_r}{MP_m})$.

$a_5=a_1^2m_1^2$; $a_6=a_2^2m_2^2$; $a_7=2a_1a_2m_1m_2$; $a_8=a_3S_c^2a_9=a_4^2p_1^2, a_{10}=2a_3a_4S_cP_r, a_{11}=2a_1a_3m_1S_c$, $\mathrm{a}_{12}=2\mathrm{a}_1\mathrm{a}_4\mathrm{m}_1\mathrm{P_r}, \mathrm{a}_{13}=12\,\mathrm{a}_2\mathrm{a}_3\mathrm{m}_2$,

$\mathrm{a}_{14}=-2\mathrm{a}_2\mathrm{a}_4\mathrm{m}_2\mathrm{P_r}$, $\mathrm{a}_{15}=\frac{-P_ra_5}{4m_1^2-P_r2m_1}$,$\mathrm{a}_{16}=\frac{-P_ra_6}{4m_1^2-P_r2m_1}$, $\mathrm{a}_{17}=\frac{-P_ra_7}{4m_1^2-P_r2m_1}$, $\mathrm{a}_{18}=\frac{-P_ra_8}{4m_1^2-P_r2m_1}$, $\mathrm{a}_{19}=\frac{-P_ra_9}{4m_1^2-P_r2m_1}$, $\mathrm{a}_{20}=\frac{-P_ra_{10}}{4m_1^2-P_r2m_1}$,

$\mathrm{a}_{21}=\frac{-P_ra_{11}}{4m_1^2-P_r2m_1}$, $\mathrm{a}_{22}=\frac{-P_ra_{12}}{4m_1^2-P_r2m_1}$, $\mathrm{a}_{23}=\frac{-P_ra_{13}}{4m_1^2-P_r2m_1}$, $\mathrm{a}_{24}=\frac{-P_ra_{14}}{4m_1^2-P_r2m_1}$, $\mathrm{a}_{25}=\frac{MP_mG_r}{(2m_1)^3+k_6(2m_1)^2+k_7(2m_1)}$, $\mathrm{a}_{26}=\frac{MP_mG_r}{(2m_2)^3+k_6(2m_2)^2+k_7(2m_2)}$,

$\mathrm{a}_{27}=\frac{MP_mG_r}{(m_{1+m_2})^3+k_6(m_1+m_2)^2+k_7(m_1+m_2)}$, $\mathrm{a}_{28}=\frac{MP_mG_r}{(-2S_c)^3+k_6(-2S_c)^2+k_7(-2S_c)}$, $\mathrm{a}_{29}=\frac{MP_mG_r}{(2P_r)^3+k_6(2P_r)^2+k_7(2P_r)}$, $\mathrm{a}_{30}=\frac{MP_mG_r}{(P_r-S_c)^3+k_6(P_r-S_c)^2+k_7(P_r-S_c)}$,

$\mathrm{a}_{31}=\frac{MP_mG_r}{(m_1-S_c)^3+k_6(m_1-S_c)^2+k_7(m_1-S_c)}$, $\mathrm{a}_{32}=\frac{MP_mG_r}{(m_1+P_r)^3+k_6(m_1+P_r)^2+k_7(m_1+P_r)}$, $\mathrm{a}_{33}=\frac{-MP_mG_r}{(m_2-S_c)^3+k_6(m_2-S_c)^2+k_7(m_2-S_c)}$,

$\mathrm{a}_{34}=\frac{-MP_mG_r}{(m_2+P_r)^2+k_6(m_2+P_r)+k_7(m_2+P_r)}$, $b_1=c_1m_3$, $b_2=(k_{5-}c_1)m_1$, $b_3=-k_3P_r$, $b_4=-k_4S_c$, $b_6=\frac{-P_rb_1^2}{P_m(4m_3^2-P_r2m_3)}$,

$b_7=\frac{-P_rb_2^2}{P_m(4m_4^2-P_r2m_4)}$ $b_8=\frac{-P_r2b_1b_2}{P_m\{(m_3+m_4)^2-P_r(m_3+m_4)\}}$,

$b_9=\frac{-P_rb_3^2}{P_m\{(2P_r)^2-P_r(2P_r)\}}$, $b_{10}=\frac{-P_rb_4^2}{P_m[(-2S_c)^2-P_r(-2S_c)]}$,

$b_{11}=\frac{-P_r2b_3b_4}{P_m[(P_r-S_c)^2-(P_r-S_c)P_r]}$, $b_{12}=\frac{-P_r2b_1b_3}{P_m[(m_3+P_r)^2-P_r(m_3+P_r)]}$, $b_{13}=\frac{-P_r2b_1b_4}{P_m[(m_3-S_c)^2-P_r(m_3-S_c)]}$, $b_{14}=\frac{-P_r2b_2b_3}{P_m[(m_4+P_r)^2-P_r(m_4+P_r)]}$, $b_{15}=\frac{-P_r2b_2b_4}{P_m[(m_4-S_c)^2-P_r(m_4-S_c)]}$,

$b_{16}=\frac{MP_mG_r}{(2m_4)^2+k_6(2m_4)^2+k_7(2m_4)}$, $b_{17}=\frac{MP_mG_r}{(m_3+m_4)^2+k_6(m_3+m_4)+k_7(m_3+m_4)}$, $b_{18}=\frac{MP_mG_r}{(2P_r)^3+k_6(2P_r)+k_7(2P_r)}$, $b_{19}=\frac{MP_mG_r}{(-2S_c)^3+k_6(-2S_c)+k_7(-2S_c)}$, $b_{20}=\frac{MP_mG_r}{(P_r-S_c)^3+k_6(P_r-S_c)+k_7(P_r-S_c)}$, $b_{21}=\frac{MP_mG_r}{(m_3+P_r)^3+k_6(m_3+P_r)+k_7(m_3+P_r)}$, $b_{22}=\frac{MP_mG_r}{(m_3-S_c)^3+k_6(m_3-S_c)+k_7(m_3-S_c)}$, $b_{23}=\frac{MP_mG_r}{(m_3+P_r)^3+k_6(m_3+P_r)+k_7(m_3+P_r)}$, $b_{24}=\frac{MP_mG_r}{(m_3-S_c)^3+k_6(m_3-S_c)+k_7(m_3-S_c)}$

$T_1=c_4e^{p_ry}+a_{15}e^{m_1y}+a_{16}e^{m_2y}+a_{17}e^{(m_1+m_2)y}+a_{18}e^{-2s_cy}+a_{19}e^{p_ry}+a_{20}e^{(p_r-s_c)y}+a_{21}e^{(m_1-s_c)y}+a_{22}e^{(m_1+p_r)y}-a_{23}e^{(m_2-s_c)y}-a_{24}e^{(m_2+\mathrm{p_r})y}+b_5e^{2m_3y}+b_6e^{2m_4y}+b_7e^{(m_3+m_4)y}+b_8e^{2p_ry}+b_9e^{-2s_cy}+\mathrm{b1}b_{10}e^{(p_r-s_c)y}+b_{11}e^{(m_3+p_r)y}+b_{12}e^{(m_3-s_c)y}+b_{13}e^{(m_3+\mathrm{p_r})y}+b_{14}e^{(m_3-Sc)y}$.

H_1=$c_6e^{m_5y}+c_7e^{m_6y}+c_8e^{p_ry}+a_{25}e^{2m_1y}+a_{26}e^{2m_2y}+a_{27e(m_1+m_2)y+\mathrm{a28}}a_{28}e^{-2s_cy}+a_{29}e^{2p_ry}+a_{30}e^{(p_r-s_c)y}+a_{31}e^{(m_1-s_c)y}+a_{32}e^{(m_1+m_2)y}-a_{33}e^{(m_2-s_c)y}-a_{34}e^{(m_2+\mathrm{p_r})y}+b_{15}e^{2m_3y}+b_{16}e^{m_4y}+\mathrm{b17}e^{(m3+m4)y}+b_{18}e^{2p_ry}+\mathrm{b19}b_{24}e^{-2s_cy}+b_{20}e^{(p_r-s_c)y}+b_{21}e^{(m_3+\mathrm{p_r})y}+b_{22}e^{(m_3-\mathrm{s_c})y}+\mathrm{b23}b_{23}e^{(m_3+\mathrm{p_r})y}+b_{24}e^{(m_3-s_c)y}$.

$u_1=-\frac{1}{Mp_m}(c_6m_5e^{m_5y}+c_7m_6e^{m_6y}+c_8p_re^{p_ry}+a_{25}2m_1e^{2m_1y}+a_{26}2m_2e^{2m_2y}+a_{27}(m_1+m_2)e^{(m_1+m_2)y}+a_{28}(\text{-2Sc})e^{-2s_cy}+a_{29}2e^{2p_ry}+a_{30}(p_r-s_c)e^{(p_r-s_c)y}+a_{31}(m_1-s_c)e^{(m_1-s_c)y}+a_{32}(m_1+p_r)e^{(m_1+p_r)y}-a_{33}(m_2-s_c)e^{(m_2-s_c)y}-a_{34}(m_2+p_r)e^{(m_2+\mathrm{p_r})y}+b_{15}2m_3e^{2m_3y}+b_{16}m_4e^{2m_4y}+b_{17}(m_3+m_4)e^{(m_3+m_4)y}+b_{18}2p_re^{2p_ry}+b_{19}(-2s_c)e^{(-2s_cy)}+b_{20}(p_r-s_c)e^{(p_r-s_c)y}+b_{21}(m_3+p_r)e^{(m_3+\mathrm{p_r})y}+b_{22}(m_3-s_c)e^{(m_3-s_c)y}+b_{23}(m_3+p_r)e^{(m_3+\mathrm{p_r})y}+b_{24}(m_3-s_c)e^{(m_3-s_c)y}]-\frac{1}{M}[c_6e^{m_5y}+c_7e^{m_6y}+c_8e^{p_ry}+a_{25}e^{m_1y}+a_{26}e^{2m_2y}+a_{27}e^{(m_1+m_2)y}+a_{28}e^{-2s_cy}+a_{29}e^{2p_ry}+a_{30}e^{(p_r-s_c)y}+a_{31}e^{(m_1-s_c)y}+a_{32}e^{(m_1+\mathrm{p_r})y}-a_{33}e^{(m_2-s_c)y}-a_{34}e^{(m_2+\mathrm{p_r})y}+b_{15}e^{2m_3y}+b_{16}e^{2m_4y}+b_{17}e^{(m_3+m_4)y}+b_{18}e^{2p_ry}+b_{19}e^{-2s_cy}+b_{20}e^{(p_r-s_c)y}+b_{21}e^{(m_3+\mathrm{p_r})y}+b_{22}e^{(m_3-s_c)y}+b_{23}e^{(m_3+p_r)y}+b_{24}e^{(m_3-s_c)y})$

$c_{71}=((c_8+a_{25}+a_{26}+a_{27}+a_{28}+a_{29}+a_{30}+a_{31}+a_{32}-a_{33}-a_{34}+b_{15}+b_{16}+b_{17}+b_{18}+b_{19}+b_{20}+b_{21}+b_{22}+b_{23}+b_{24}))\ m_5$

$c_{72}=c_8p_r+a_{25}\ 2\ m_1+a_{26}\ 2\ m_2+a_{27}\ (m_1+m_2)+a_{28}\ (\text{-2}\ s_c)$:

$c_{73}=2\ p_ra_{29}+a_{30}\ (p_r-s_c)+a_{31}\ (m_1-s_c)+a_{32}\ (m_1+p_r)-a_{33}\ (m_2-s_c)-a_{34}\ (m_2+\mathrm{Pr})+b_{15}\ 2\ m_3+b_{16}\ 2\ m_4+b_{17}\ (m_3+m_4)+b_{18}\ 2\ p_r$:

$c_{74} = b_{19}\,(-2\ s_c) + b_{20}\,(p_r - s_c) + b_{21}\,(m_3 + p_r) + b_{22}\,(m_3 - s_c) + b_{23}\,(m_3 + p_r)$ + b24 $b_{24}\,(m_3 - s_c)$:

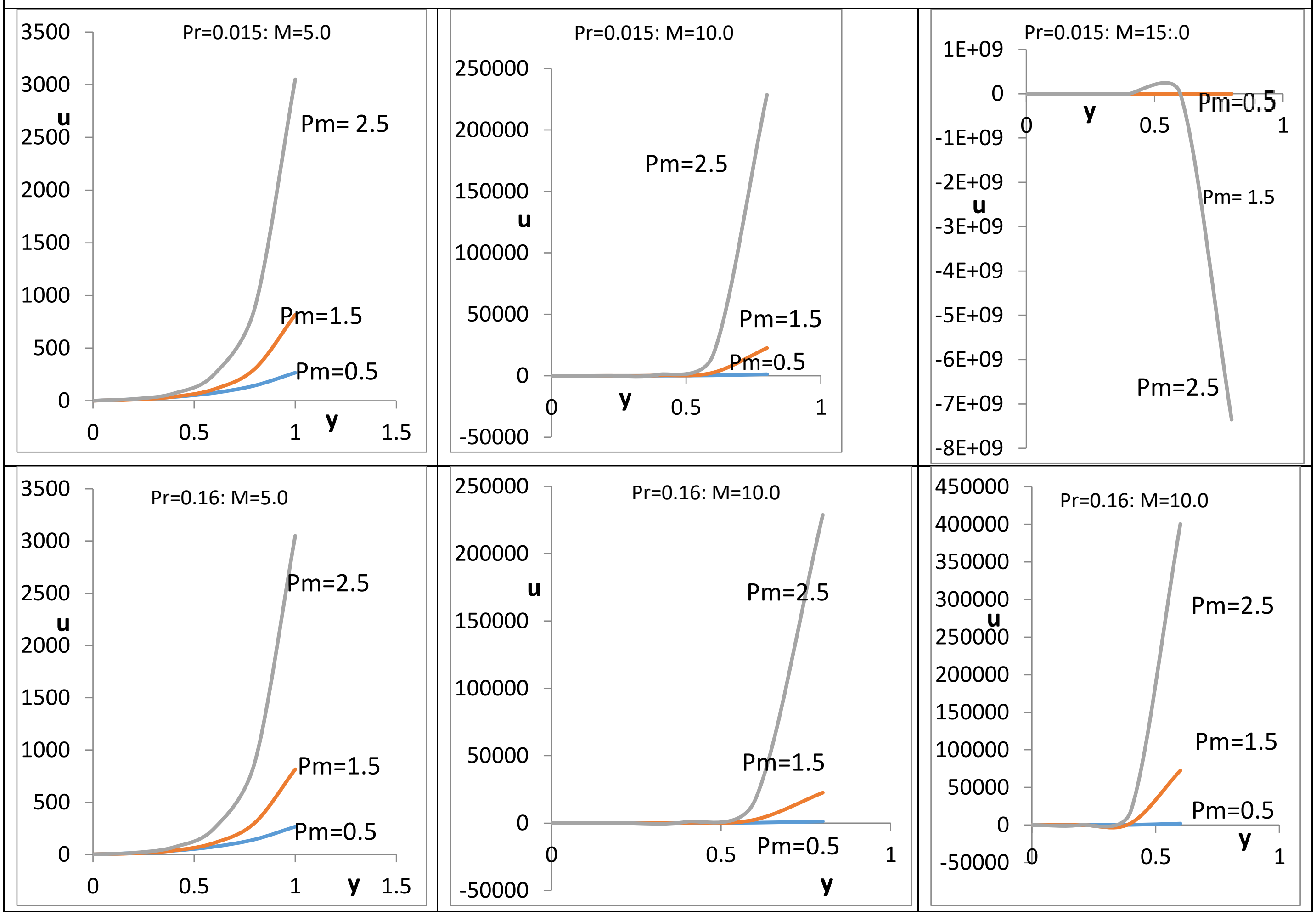
$c_7 = (1 / (m_5 - m_6))\,(c_{72} + c_{73} + c_{74} - c_{71})$:

$c_6 = -(c_7 +$ c8 $+ a_{25} + a_{26} + a_{27} + a_{28} + a_{29} + a_{30} + a_{31} + a_{32} - a_{33} - a_{34} + b_{15} + b_{16} + b_{17} + b_{18} + b_{19} + b_{20} + b_{21} + b_{22} + b_{23} + b_{24}))$

9. RESULT AND DISCUSSION

The purpose of study is to discuss the effects of induced field (p_m) and mass transfer (S_c) on velocity field(u), temperature field (T), magnetic field (H), skin friction at the plate $[\tau]_{y=0}$, and the rate of heattransferat the plate $[Q]_{y=0}$. In calculating numerical values of the physical quantities u, H, T, $\frac{du}{dy}$, $\frac{dT}{dy}$, τ and Q, we have considered Gm = 4 (arbitarily); E=0.001 so to satisfy the series expansion [13]; Gr = 10 because it relates to the various problems in engineering and technologycal activities; Mass transfer parameter Sc varied as 0.22 (for Hydrogen), 0.6 (for Water vapour) & 0.75 (for Oxygen). The physical parameters whose effects on flow are the objectives of this study i.e the induced field parameter Pm (Magnetic Prandtl Number)is varied as 0.5 to 4.5 while applied field parameter M (Hartmann Number) is varied from 5.0 to 20.0; We consider that Pm ≤ 0.5 means slow affect of induced field while Pm ≥ 2.5 moderate affect of the induced field. Further the parameter relates viscous with thermal diffussion i.e. Prandtl Number (Pr) is varied as 0.015 (for mercury) , 0.16 (for noble gase), 0.7 (for water at 20 ^{0} c).Following are the results from the figures (1-5) drawn using numerical values of the physical parameters given above.

Fig. 1(i – ix): Velocity Profile, variation of u with Pm for Sc = 0.22; Gr=10; Gm =4; U=1; K=.5; E=0.001;



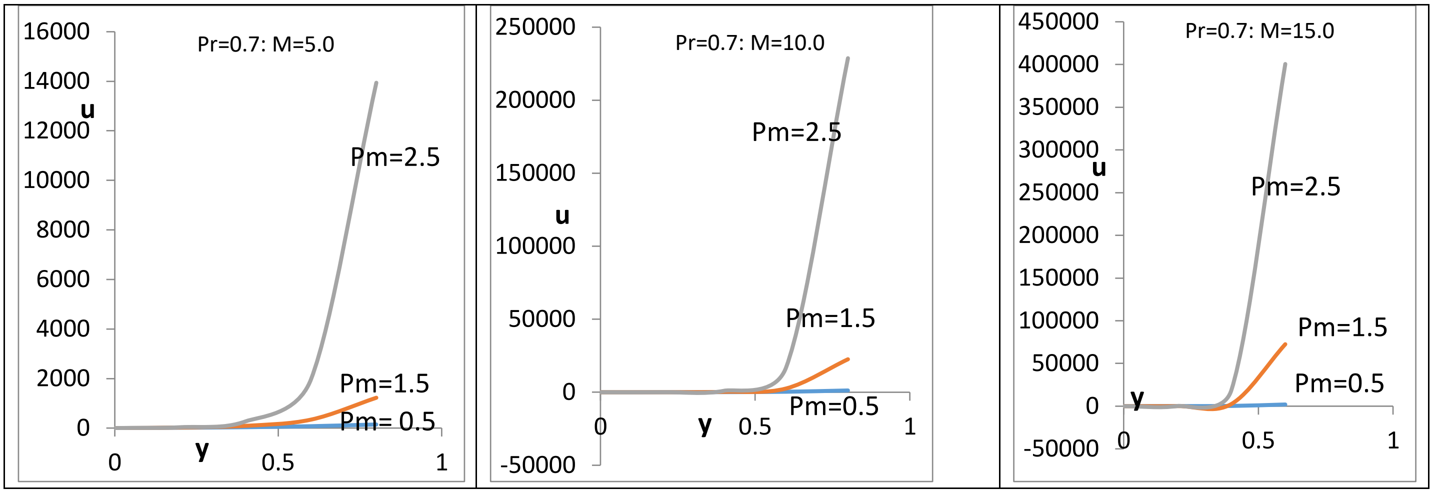
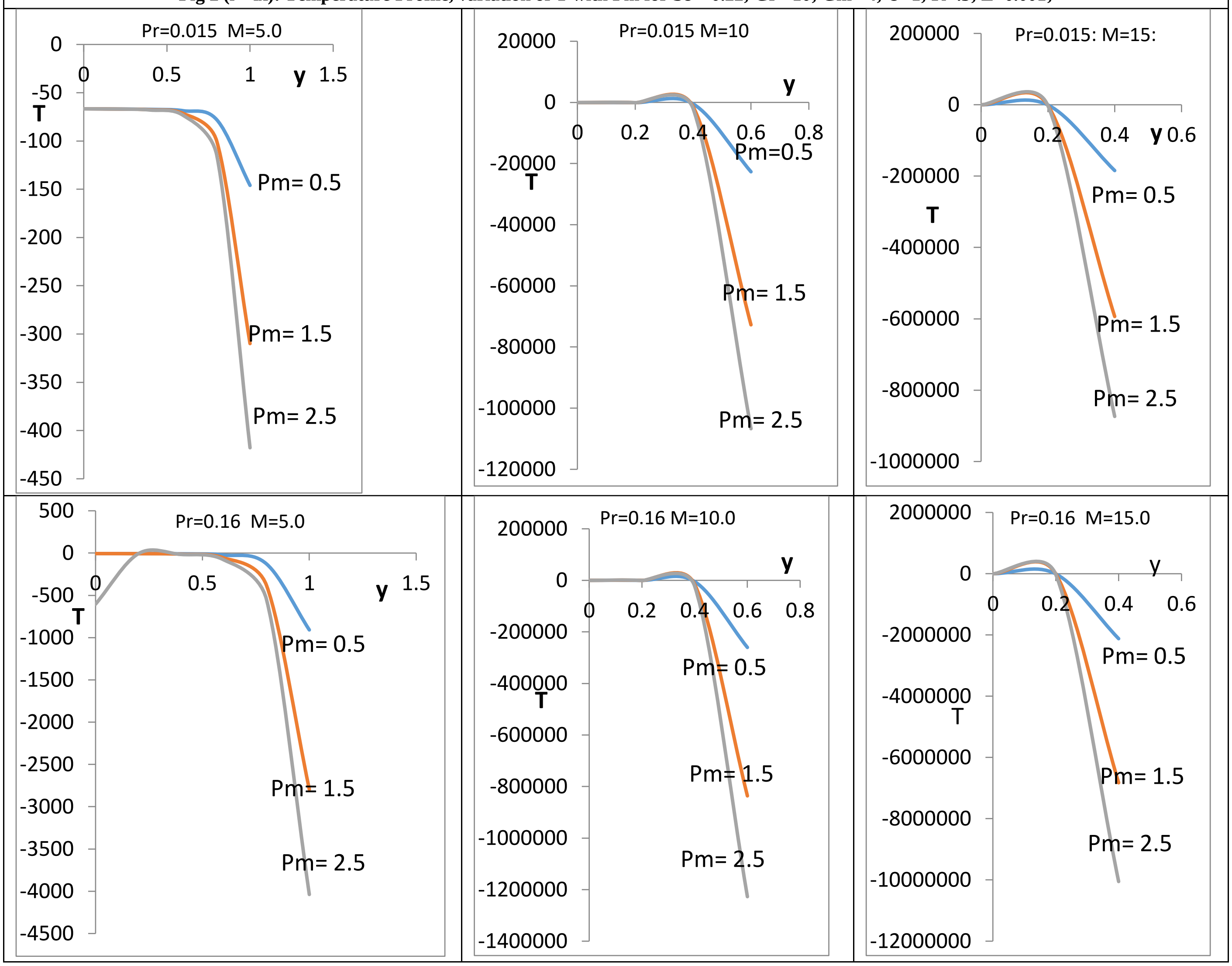


Fig 1. Shows variation of fluid velocity with Pm, M & Pr. It is clear from the figures that when M remains unchanged, u increases with Pm; the rate of increase is higher for higher values of Pm. keeping Pm constant, and M rises up, u increases with largely; e.g. at y = 1.0, & Pm = 1.5, u = 815.7 for M=5.0 while u = 22581.4 for M = 10.0; similarly for Pm = 0.5 and Pm = 2.5. For higher values of M (> 10) and lower value of Pr, velocityu reverses its direction. The variation of u with Pm almost same in nature when Pr increases, keeping M unchanged.

Fig 2 (i – ix): Temperature Profile, variation of T with Pm for Sc = 0.22; Gr =10; Gm =4; U=1; K=.5; E=0.001;



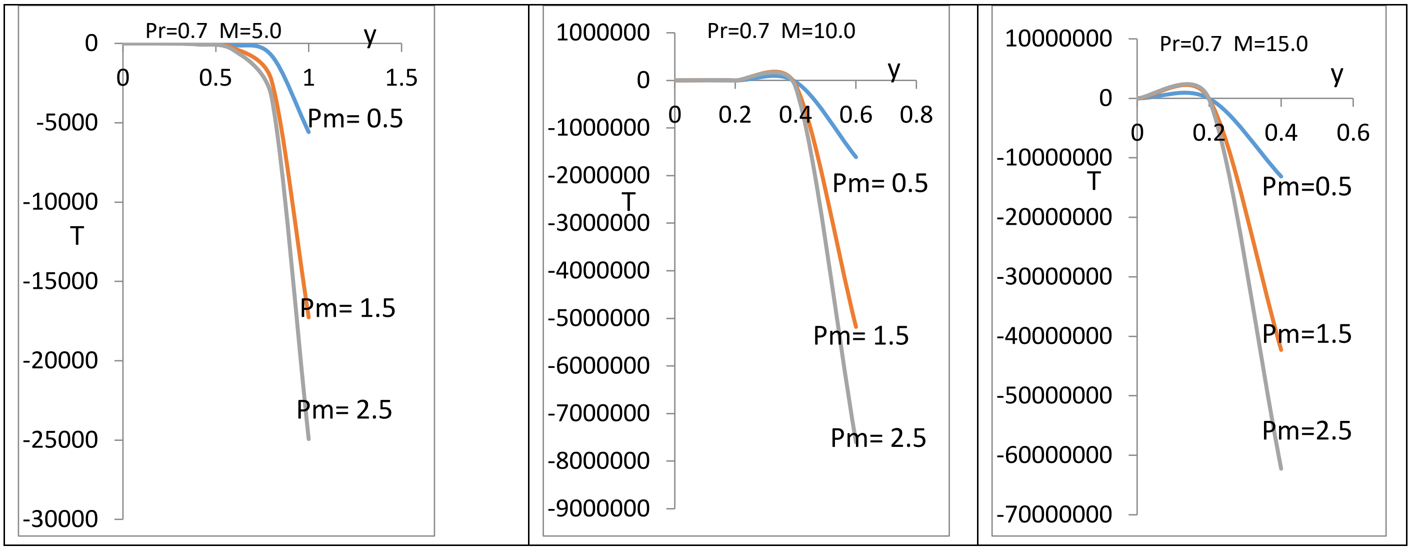


Fig 2. Show variation of fluid Temperature (T) with Pm, M & Pr. The figures show that within the medium, T decreases with the rise of Pm for all values of M (= 5.0, 10.0, 15.0) & Pr (= 0.015, 0.16, 0.7). Keeping Pm constant, T decreases with increase of M largely (e.g. at y = 0.8 & Pm = 1.5, T = -100.26 for M=5.0 while T = -3968069.0 for M = 10.0; similarly for Pm = 0.5 and Pm = 2.5); this implies higher rate of heat transfer -$[\frac{dT}{dy}]$ at higher values of M. When M & Pm are at constant, T decreases with increase of Pr ; this implies lower the thermal diffusion, lower fluid temperature. The nature of variation of T with Pm at constant M is almost same for different higher values of Pr (= 0.015, 0.16, 0.7).

Fig 3 (i – iii): Magnetic field Profile variation of H with Pm, for Sc = 0.22; Gr=10; Gm =4; U=1; K=.5; E=0.001;

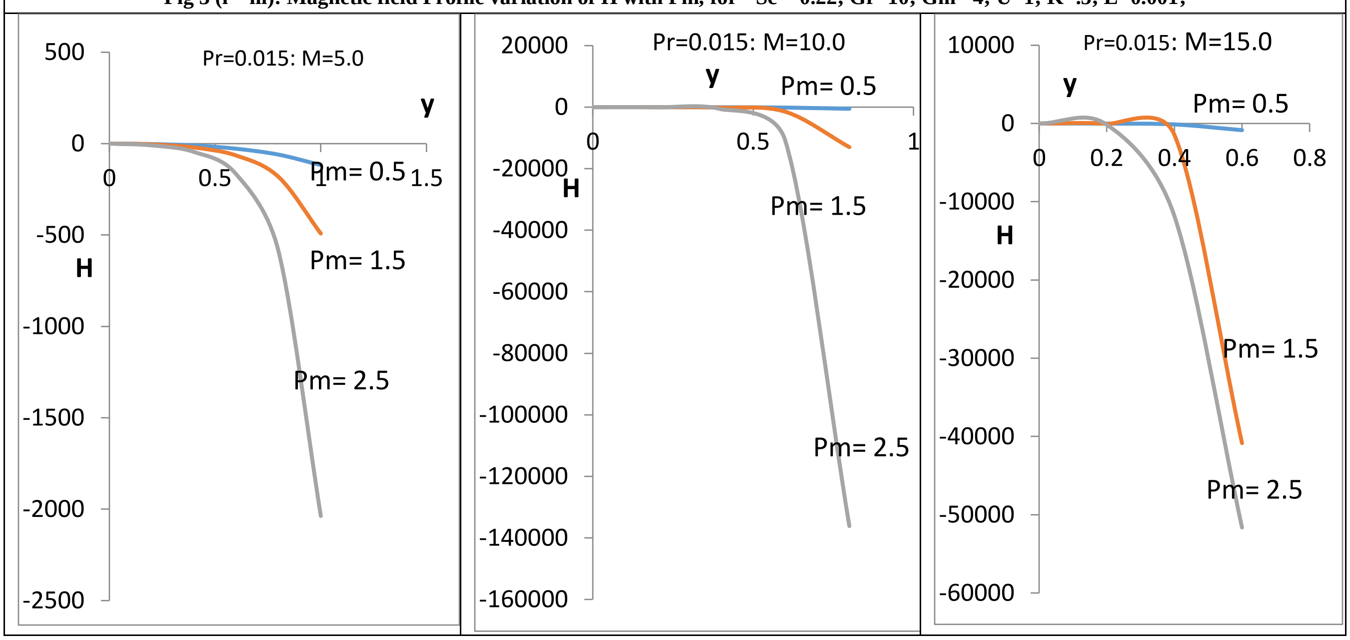


Fig 3. Show variation of magnetic field with Pm, M & Pr. Away from the plate, H decreases for all values of M,Pm & Pr ; the rate of decrease is more when Pm is higher; similarly for M when Pm is constnt. Field a very near to the plate is less variant of Pm depending upon applied field (e.g. field is less variant within $y \leq 2.0$ when M = 5.0 while it is $y \leq 5.0$ when M = 10). When M increases at constant Pm, H decreases largely (e.g. at y = 0.4, & Pm = 1.5; H = -21.022 for M=5.0 while H = -162.344 for M = 10.0 and H = --1437.68 for M = 15.0); similarly for Pm = 0.5 and Pm = 2.5.

Fig 4 (i – ix): Shear Stress (τ), variation with Pm & M for Sc = 0.22; Gr =10; Gm =4; U=1; K=.5; E=0.001;

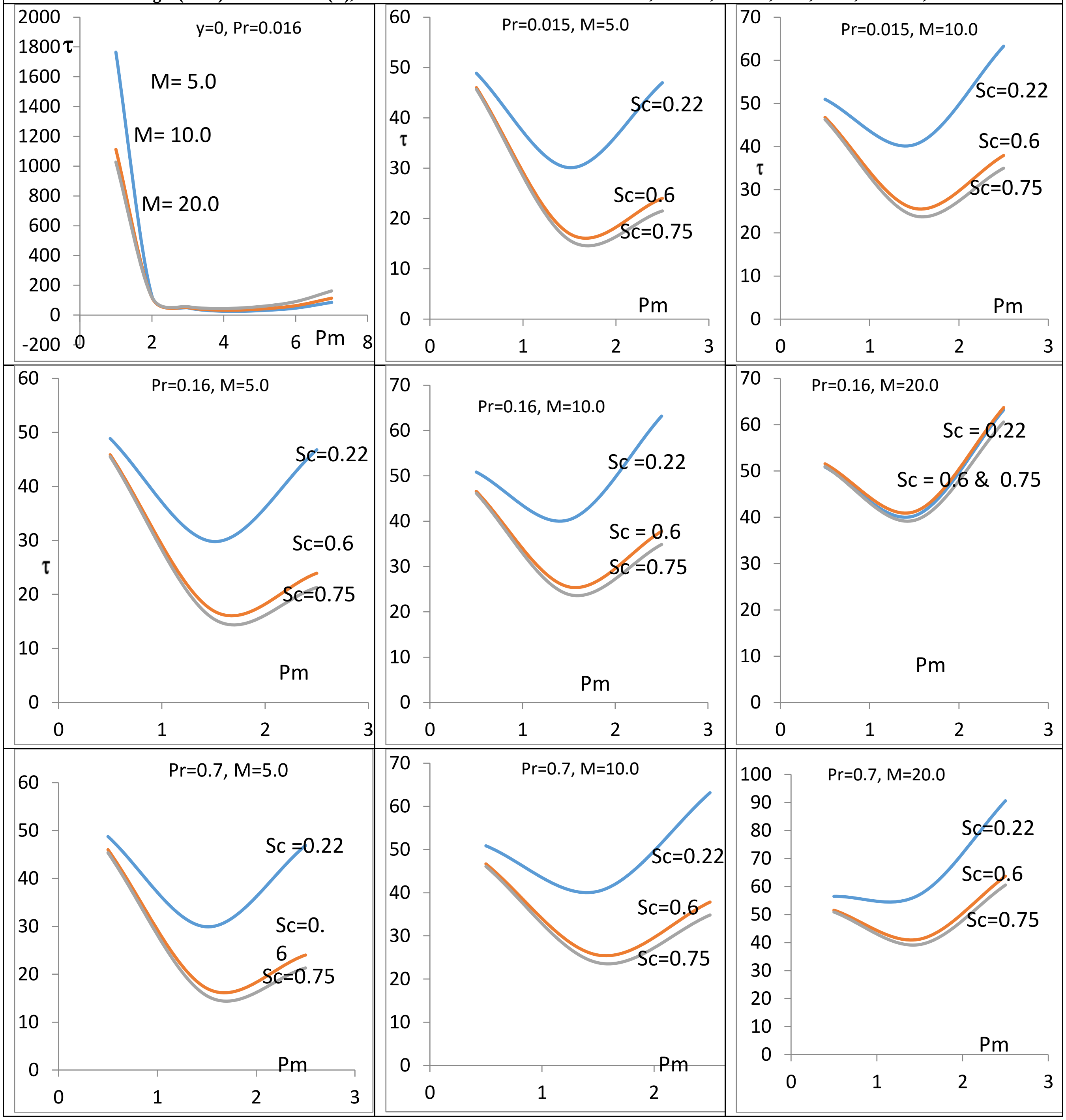


Fig 4. Show variation of Shear stress (τ) experienced by the fluid motion at the plate (y=0) with Pm, M & Pr. τ at the plate y = 0, varies inversely with Sc when M, Pm &Pr are fixed. For all values of M, τ decreases rapidly with the increase of Pm within lower values of Pm ≤2.0 (approx.), while increases slowly beyond it. When Pm, M &Pr are constant, τ increases with the rise of M ; decreases with rise of Sc at constant Pm, Pr& M. When field is high M ≥20 , the variation of τ with Sc becomes less significant but becomes prominent when both M &Pr are high. This implies the strong effect of Pron τ.

Fig 5: Rate of heat transfer, proportional to ($\frac{dT}{dy}$) Variation with Pm & M for Gr=10; Gm =4; U=1; K=.5; E=0.001;

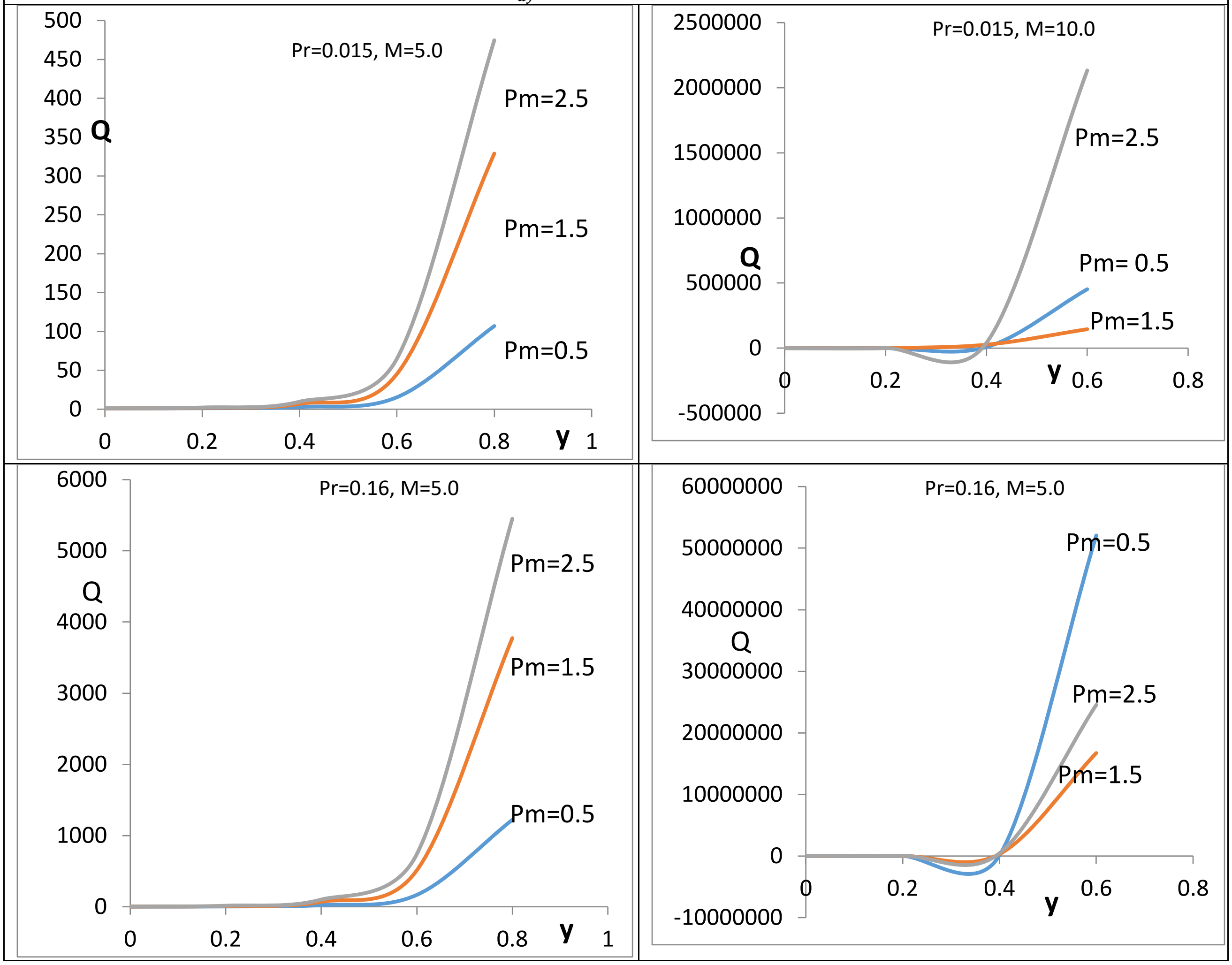


Fig 5. Show variation of Q away from the plate. A little away from the plate y >0 (depending upon M), Q is less variant for the variation of Pm and Pr (e.g. for M= 5.0, $y \leq 4.0$ aprox. while M= 10.0, $y \leq 2.0$ aprox.); beyond this, Q increases sharply with the increase of Pm. The limiting value of y beyond which Q varies linearly with Pm depends upon M. The rate of increase of Q within the medium is more when Pm is higher. The variation of Q within the medium is higher when either of M &Pr is higher and when both M &Pr are higher Q is much higher within the medium.

10. CONCLUSION

- Applied field(H), Induced field (Pm) and thermal diffusivity factor (Pr) have influence over fluid velocity. Fluid velocity increases with the increase of applied field and induced field. The direction of fluid velocity reverses when M & Pm is higher but Pr is lower.
- The effect of H, Pm ,Pr on Fluid temperature (T) is opposite in nature to the variation of velocity as above. Temperature is much low when all the three parameters Pm, M &Pr are higher. This implies strong thermal diffusivity effect with magnetic interaction and also higher rate of heat transfer within the medium.
- Away from the plate, Magnetic field within the medium decreases with the rise of induced field; this implies strong magnetic diffusivity within the medium away from the plate. At very close to the plate, magneric field is almost uniform (i.e. less variant with induced field) depending upon applied field.
- The effect of applied field on shear stress significantly depends upon induced field. The nature of variation of shear stress is almost opposite within lower level of induced field and beyond it; the level depends upon applied field. Bothinduced field and mass transfer parameter have significant role over the shear stress.
- Applied field, Induced field and thermal diffusivity factor have distinctive influence over the heat transfer. Heat transfer is more at higher induced field. It is further higherwhen thermal diffusivity factor (Pr) is higher along with higher applied field (H)but less induced field(Pm); this implies higher rate thermal and magnetic interaction.

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